Neutron Flux and Cadmium Ratio Measurement of the Co-axial Cylindrical Neutron Generator

M. S. Basunia[1], H. A. Shugart[2], J. Reijonen[3], F. Gicquel[3], and R. B. Firestone[1]

[1] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

[2] *Department of Physics, UC Berkeley, Berkeley, CA 94720*

[3] *Accelerator and Fusion Research Division, Berkeley National Laboratory, Berkeley, California 94720*

The D+D compact neutron generator (NG) at Lawrence Berkeley National Laboratory (LBNL) has been a key interest for various neutron based researches and analytical applications. Neutron activation analysis (NAA) and prompt gamma neutron activation analysis (PGNAA) are two widely used non-destructive nuclear methods for major and trace elemental determination in different matrix samples through neutron induced reactions. The knowledge of neutron flux ($n.cm^{-2}.sec^{-1}$) data at different energies is important for any sample analysis by NAA and PGNAA methods. The cadmium ratio is an important parameter for neutron spectrum characterization, useful both for NAA and neutron radiography experiments. We have measured the neutron flux for thermal and fast neutrons using the $^{115}In(n,\gamma)^{116m}In$ and $^{115}In(n,n')^{115m}In$ (threshold E_n=0.5 MeV[1]) reactions, respectively, at different locations around the neutron generator.

The compact D+D neutron generator is surrounded by a 30 cm thick shielding of polyethylene that serves also as moderator, on all sides except the aluminum base. Half of the shielding is fixed and the other half is movable for access to the neutron generator. Open space around the cylindrical (radius ≈15 cm) neutron generator is available inside the shielding. A pneumatic irradiation facility is installed beside the neutron generator for short lived radioisotope determination. A polyethylene plug, ≈13 cm in diameter, faces the neutron generator through the shielding in one side. Indium wire of 99.9% purity and ≈1 mm diameter was coiled into a ~1.25 cm diameter disk. Five coils weighing from 1.285- to 1.654-g were placed for irradiation at the pneumatic terminal, at the inside shielding wall, on top of the neutron generator, and the remaining two on the access plug facing the neutron generator with and without the cadmium cover of ~1 mm thickness. Indium coils were irradiated for 4 hours with a 40 mA deuteron beam current and 80-kV acceleration potential. The growth of D+D neutrons was monitored by a neutron detector coupled to a screen display, and steady state neutron production was reached within 15 minutes.

Irradiated samples were counted with an HPGe spectrometry system at building 88, LBNL, for gamma rays. A partial gamma ray spectrum is shown in FIG. 1. The neutron flux was determined from the well known activation equation:

$$A_o = n\sigma\phi\left(1-e^{-\lambda t}\right) \quad \text{----------} (1)$$

where, A_o = radioisotope activity at the end of irradiation, n = # of target nuclei, σ = cross section, ϕ = neutron flux, λ = decay constant, and t=irradiation time. The end activity, A_o, was calculated using the following equation:

$$A_o = \lambda N_o = \lambda C \Big/ \left\{ I_\gamma \varepsilon \left(e^{-\lambda(t_{cs}-t_{ie})} - e^{-\lambda(t_{ce}-t_{ie})} \right) \right\} \text{--}(2)$$

where, N_o = number of product nuclei at the end of irradiation, t_{cs}, t_{ce}, t_{ie} = counting start, counting end, and irradiation end times, respectively, C = net area, under the peak for a counting duration (t_{cs} - t_{ce}), I_γ = gamma ray intensity, and ε = detector efficiency.

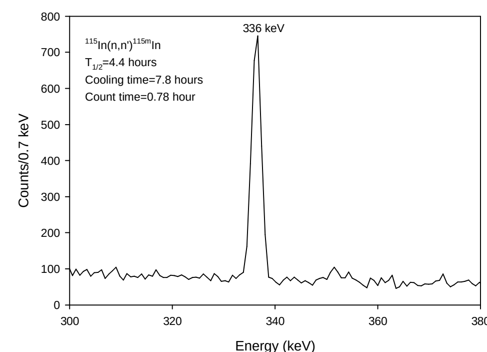

FIG. 1: Partial gamma ray spectrum of the ^{115m}In decay.

For determining the thermal and fast neutron fluxes, average cross sections of 162.3 barns [2] and 0.3 barn (estimated average for 2– to 3–MeV neutrons), respectively, were used in equation (1). The deduced results of the neutron flux are presented in Table 1.

The ratio of the $^{115}In(n,\gamma)^{116m}In$ reaction rates (RR), $A_o = n\sigma\phi$, without and with the Cd cover gives a cadmium ratio ($R=RR^*_B/RR_{Cd}$) of 9. Usually for a 1-mm thick Cd shielding, all neutrons with energies ≤0.5 eV are absorbed.

Table 1: Neutron flux ($n.cm^{-2}.sec^{-1}$) at different locations around the NG, uncertainty ≈20%.

Sample location	Distance from the center of the NG cylinder	Thermal neutron flux	Fast neutron (>0.5 MeV) flux
Pneumatic terminal	≈28.2 cm	1.1E+04	1.4E+05
Inner shielding	≈26.2 cm	1.3E+04	1.0E+05
Top of the NG		1.1E+04	1.5E+05

The thermal neutron flux is found to be consistent with an earlier report [3]. A simple estimate of the total neutron production from the measured fast neutron flux using the $1/4\pi r^2$ term implies ≈10^9 n/sec at the central point of the neutron generator. Theoretical verification of the experimental results will be done at a future time using the MCNP code.

REFERENCES

[1] L. Kuijpers, R. Herzing, P. Cloth, D. Filges and R. Hecker, Nuclear Instruments and Methods, 144, 215-224, 1977.

[2] Mughabghab S.F., M. Divadeenam, and N.E. Holden (1981) Neutron Cross-Sections, Vol. 1 and 2, Academy Press.

[3] R. B. Firestone, *et al.*, NSD annual report, LBNL, 2003.